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An Integrated Technique for Evaluating Root Growth Potential of Tree Seedlings

W. J. Rietveld and Richard W. Tinus[1]

Root growth potential (RGP) is an important seedling quality attribute, but a more efficient testing technique is needed for RGP to gain wide acceptance. A method is described in which seedlings are grown aeroponically in a root misting chamber and root growth, expressed as change in root area index, is measured using a video camera and area measurement system. The method consists of: (1) premeasuring root area index of individual seedlings, (2) growing the seedlings aeroponically, (3) remeasuring root area index of individual seedlings, and (4) calculating root growth as change in root area index. Test duration is about 2 weeks and as many as 500 seedlings a day can be measured by one person, but the actual numbers will depend on species.

Keywords: Planting stock quality, aeroponic culture, root area index, root growth capacity.

Introduction

Stone (1955) first reported that survival of transplanted tree seedlings is highly dependent on their ability to regenerate new roots. The measure of this ability, called root growth potential (RGP), is an important seedling quality attribute that is often correlated with seedling survival in the field and is sometimes a good predictor of growth after planting (Ritchie 1985). The original RGP test (Stone and Schubert 1959) consists of: (1) removing all existing white root tips, (2) potting seedlings in a well-aerated medium, (3) growing them in a favorable environment for 28 days, and (4) unpotting the seedlings and determining the total number and/or total length of new white roots. For comparability among RGP tests, it is very important that soil temperature, soil moisture and aeration, humidity, air temperature, and photoperiod be favorable for the species tested and repeatable if a series of tests will be run and the results compared (Ritchie and Dunlap 1980, Thompson and Timmis 1978).

The original potting method has several disadvantages: (1) it requires substantial quantities of potting soil and greenhouse space; (2) the seedling population is divided among several containers, which may increase variation; (3) potting and unpotting seedlings, and root measuring and counting, are laborious and time consuming; and (4) results are not available for 1 month.

Numerous variations on the original RGP test have been developed that simplify or automate the tasks of growing the seedlings or quantifying root growth. Alternative growing methods include hydroponic culture (DeWald et al. 1985, Ritchie 1984) and aeroponic culture (Harvey and Day 1983). Advantages of hydroponic and aeroponic culture over soil culture are: (1) fewer containers are used to grow the seedlings, so variation is reduced; (2) they avoid using large amounts of potting medium and greenhouse space; (3) less time is needed to put the seedlings in and take them out of the system; (4) the progress of rooting is easily monitored; and (5) breakage of new roots is minimized. The complexity and cost of the three cultural systems is similar if a water bath system is used with soil culture. Although fertilization is unnecessary in a short-term test, it is most easily done in soil culture.

Alternative methods to measure root growth include counting only number of roots that exceed a minimum length (Stone and Schubert 1959); clipping, drying, and weighing the new roots (Rietveld and Williams 1981);

[1]Supervisory Plant Physiologists, Rocky Mountain Forest and Range Experiment Station, Lincoln, NE, and Flagstaff, AZ, respectively. Headquarters is in Fort Collins, in cooperation with Colorado State University.

measuring root volume increase (Burdett 1979b); using a scoring index based on number of roots exceeding a minimum length (Burdett 1979a); and increase in a root area index (Day and MacGillivray 1975). Each of these methods is useful, and many have succeeded in reducing test duration or increasing efficiency of root measurement.

This paper reports an integrated RGP technique that uses an aeroponic growing system (Rietveld 1989a) and an automated method to quantify root growth as change in root area index (Rietveld 1989b).

Equipment

The root misting chamber (fig. A-1) is an aeroponic device that maintains a constant, uniform, and repeatable temperature and high-humidity environment for the roots that are independent of the external environment. The unique feature of the aeroponic system used with this technique is a heated water reservoir in the bottom of the chamber that maintains a dominant thermal mass and preheats the misting water. Tree holders with seedlings clamped at the root collar are set on top of the chamber, suspending the roots in an intermittently misted atmosphere inside the chamber.

Root growth is quantified using a video camera and digitizing area meter (fig. B-1). A seedling root system is placed on a backlighted box in view of the video camera. The area meter sums the scanning line segments that are covered by roots and superimposes the area on the image displayed by a monitor. The system is calibrated (appendix B) to measure a root area index (root area in two dimensions) by adjusting the displayed area to agree with the scanned area of an object of known area. Root growth of individual seedlings is quantified as change in root area index, i.e., the difference between a pretest area measurement and a posttest measurement. Optionally, data can be transmitted via a serial port on the area meter to a portable data collector and the completed data file uploaded to a computer (Rietveld and Ryker 1987, appendix B).

Technique

Prepare seedlings.—Depending on the uniformity of the test plants and precision desired, a sample of 10–50 seedlings is necessary. Seedlings should be root-pruned to a standard length normally used at the nursery, washed, and individually numbered. Any existing white root tips should be pinched off.

Measure pretest root area index.—A seedling root system is placed on the light box so that the image of the roots is perpendicular to the horizontal TV lines. The intersection of the first lateral root with the taproot is aligned with the edge of the viewing area as a reference point in repeat measurements. Roots are spread out to a reasonable extent to minimize overlaps. Three area measurements of each root system are taken, turning the seedling over each time.

Grow seedlings.—Sample seedlings are placed in tree holders and grown aeroponically in the root misting chamber for a predetermined time period.

Measure posttest root area index.—When a test is terminated, seedling roots must be kept moist until they are measured because drying will result in root shrinkage and a decrease in root area. The new white roots are stained dark (to make them visible to the camera) by dipping root systems in a large beaker of paragon multiple stain (7.3 g toluidine blue + 6.8 g basic fuchsin in 1,000 ml 30% ethanol). The seedlings are dipped to the root collar, rinsed, and blotted dry. Then, root area index is measured using the same reference point and repeat measurement procedure used in the pretest measurement.

Summarize data.—Change in root area index (mean posttest root area index minus mean pretest root area index) for each seedling is used as an estimate of root growth potential and may be used as an observation in statistical analyses to compare tests. Parameters that can be calculated from the test data are: (1) percent increase (or decrease) in root area index ([change in root area index/pretest root area index] × 100); (2) root area index-diameter ratio (change in root area index/root collar diameter in mm); and (3) rooting intensity (root dry weight in grams/change in root area index). While the usefulness of these parameters has not been documented, they may have application in future research to fine tune seedling characteristics to planting site conditions.

Discussion

Test conditions and length must be tailored to species. The most important factors to RGP expression are root temperature and aeration. The optimum root temperature is usually between 18°C and 25°C, depending on species (Ritchie and Dunlap 1980). For lodgepole pine (*Pinus contorta* Dougl.), Burdett (1979a) found that use of high test temperatures (30°C day/25°C night) enabled shortened test times. Though optimum test conditions will vary somewhat among species, a 20°C air and root temperature, 16-hour photoperiod, and 14- to 21-day test period are often used. If a series of RGP tests will be run and the results compared, it is strongly advised that preliminary screening tests be run to establish a set of standard testing conditions for the species being evaluated.

A key point in conducting RGP tests is that the test environment must remain constant from test to test. Although a growth chamber is the preferred equipment to satisfy that requirement, most RGP testing is done in greenhouses despite the lack of total environmental control. Growing the test seedlings in pots of growing medium in a greenhouse without any system to maintain a constant root temperature (such as a water bath) is the easiest technique, but leads to greater variability among RGP tests. Both the hydroponic method (DeWald et al. 1985, Palmer and Holen 1986) and the aeroponic method (Harvey and Day 1983, Rietveld 1989a) employ a heating system to maintain a constant root environment. Such devices work well in a greenhouse (or other loca-

tion) as long as the ambient temperature is lower than the maintained root temperature. High greenhouse temperatures are usually not a problem in the winter and spring when RGP tests are normally conducted.

In a comparison of potting, hydroponic, and aeroponic RGP tests (Rietveld 1989a), it was found that although all three methods successfully diagnosed differences in seedling vigor, root growth occurred sooner, faster, and more uniformly in the aeroponic system. Root growth was slowest in hydroponic culture, which may be due to inadequate dissolved oxygen in a boundary layer around the roots in an unstirred liquid growing medium. Soffer and Burger (1988) demonstrated the importance of adequate aeration to root formation and root growth. They found that rooting was best in aeroponic culture because of high dissolved oxygen levels, and poor in hydroponic culture unless the water is stirred constantly. The reason for the more vigorous root growth in the aeroponic system may be the exceptionally well-aerated growing environment.

Using the aeroponic system, it may be possible to reduce both sample size and test length to some extent. However, it is unlikely that test length can be reduced to less than 14 days because: (1) low vigor seedling lots and some species may take at least 14 days to exhibit a measurable response that will allow detection of differences; (2) elevating the root temperature and shortening the test period, such as the method reported by Burdett (1979a) for lodgepole pine (*Pinus contorta* Dougl.), does not work for many species (Rietveld and Tinus, unpublished data); and (3) a <14-day test period may give misleading results during cold acclimation (Burr et al. 1987). On the other hand, in longer tests (e.g., 28 days), aeroponic culture may be too favorable for root growth so that weakened seedlings may recover and show acceptable RGP (Rietveld and Tinus 1987).

There have been numerous attempts to circumvent the tedious and labor-intensive process of quantifying root growth in RGP tests. Because number of new roots and total length of new roots are highly correlated (Rietveld 1989a, 1989b; Stone and Schubert 1959), simply counting new roots results in considerable time savings. Several shortcuts on this include counting roots longer than a minimum length, measuring the 3–5 longest roots, determining the percent of seedlings tested that had any root growth, assigning response classes to seedlings based on the number and length of new roots, and comparing root growth response to reference photos (Ritchie 1985). All of these shortcuts serve to expedite the quantification process, but all are subjective, relying on the perception of the observers, which may vary considerably. Volume displacement methods (Burdett 1979b) also serve to expedite quantification of root growth, but they must be applied carefully in order to obtain consistent results (Ritchie 1985). Day and MacGillivray 1975) quantified root growth as difference in root area index using a rhizometer (Morrison and Armson 1968), but it has subsequently been reported (Racey 1985) that the rhizometer does not detect new white roots at higher light intensities.

Nearly every operation involved in RGP assessment uses some type of shortcut method to estimate the amount of new root growth. However, before adopting a shortcut measurement method, it must be determined if the relative nature of the data obtained satisfies the objectives of testing. Because of such factors as using a minimum length in root number and length measurements, root decrement in area index difference measurements, wetting and water absorption in root volume measurements, and observer subjectivity in visual methods, shortcut methods will always produce a relative estimate of root growth rather than an exact measure and will generally correlate with each other. If applied prudently and consistently, all of these methods will adequately and conveniently estimate new root growth as an indicator of seedling vigor. Where more detailed information on the origin and sizes of new roots is needed, such as in physiology research, direct inspection of root systems is unavoidable.

When a shortcut method to estimate new root growth is appropriate, change in root area index may provide a better estimate of root growth in RGP tests than other techniques because it (1) is well correlated with both number and total length of new roots (Rietveld 1989b); (2) measures all new roots, (3) takes both root diameter and length into account; (4) measures net root system growth; and (5) increases productivity to 250–500 seedlings per person per day, depending on species and seedling size. However, the root area index method (1) does not distinguish the origin of new roots, (2) does not determine the numbers of coarse and fine roots, and (3) requires more costly equipment. Thus, the method is best suited for larger operations.

Each of the alternative methods to grow seedlings and quantify root growth in RGP tests has its advantages and limitations, and there is no "best" method. The choice of method used will largely be determined on the basis of species, purpose of the tests, number of seedlings to be evaluated, time constraints, and available resources.

Literature Cited

Burdett, A. N. 1979a. New methods for measuring root growth capacity: their value in assessing lodgepole pine seedling quality. Canadian Journal of Forest Research. 9: 63–67.

Burdett, A. N. 1979b. A non-destructive method for measuring the volume of intact plant parts. Canadian Journal of Forest Research. 9: 120–122.

Burr, Karen A.; Tinus, Richard W.; Wallner, Stephen J.; King, Rudy M. 1987. Comparison of time and method of mist chamber measurement of root growth potential. In: Proceedings, Intermountain nurserymen's association meeting; 1987 August 10–14; Oklahoma City, OK. Gen. Tech. Rep. RM-151. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 77–86.

Day, R. J.; MacGillivray, G. R. 1975. Root regeneration of fall-lifted white spruce nursery stock in relation to

soil moisture content. Forestry Chronicle. 51: 196–199.
DeWald, L. E.; Feret, P. P.; Kreh, R. W. 1985. A 15-day hydroponic system for measuring root growth potential. In: Shoulders, Eugene, ed. Proceedings, 3rd biennial southern silvicultural research conference; 1984 November 7–8; Atlanta, GA. Gen. Tech. Rep. SO-54. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station: 4–10.
Harvey, E. M.; Day, R. J. 1983. Evaluating the root regeneration potential of coniferous nursery stock by the potting and root mist chamber methods. Thunder Bay, ON: School of Forestry, Lakehead University. 103 p.
Morrison, I. K.; Armson, K. A. 1968. The rhizometer—a new device for measuring roots of tree seedlings. Forestry Chronicle. 44: 21–23.
Palmer, Larry; Holen, Ivend. 1986. The aquarium tester—a fast, inexpensive device for evaluating seedling quality. Tree Planter's Notes. 37(3): 13–16.
Racey, G. 1985. A comparison of planting stock characterization with root area index, volume, and dry weight. Forestry Chronicle. 61: 64–70.
Rietveld, W. J. 1989a. Evaluation of three root growth potential techniques with tree seedlings. New Forests. 3: 181–189.
Rietveld, W. J. 1989b. Evaluating root growth potential of tree seedlings with an automated measuring system. New Forests. 3: 191–199.
Rietveld, W. J.; Ryker, Russell A. 1987. Applications of portable data collectors in nursery management and research. In: Proceedings, meeting the challenge of the nineties: Intermountain nurserymen's conference; 1987 August 10–14; Oklahoma City, OK. Gen. Tech. Rep. RM-151. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 9–13.
Rietveld, W. J.; Tinus, Richard W. 1987. Alternative methods to evaluate root growth potential and measure root growth. In: Landis, Thomas D., tech. coord. Proceedings, meeting the challenge of the nineties: Intermountain nurserymen's conference; 1987 August 10–14; Oklahoma City, OK. Gen. Tech. Rep. RM-151. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 70–76.
Rietveld, W. J.; Williams, Robert D. 1981. Lifting date affects black walnut planting stock quality. Res. Pap. NC-205. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 8 p.
Ritchie, G. A. 1984. Assessing seedling quality. In: Duryea, Mary L.; Landis, Thomas D., eds. Forest nursery manual: production of bareroot seedlings. Martinus Nijhoff/Dr. W. Junk Publishers. Corvallis, OR: The Hague Forestry Research Laboratory, Oregon State University: 243–259.
Ritchie, G. A. 1985. Root growth potential: principles, procedures and predictive ability. In: Duryea, M. L., ed. Evaluating seedling quality: principles, procedures, and predictive abilities of major tests; 1984 October 16–18; Corvallis, OR. Corvallis, OR: College of Forestry, Oregon State University: 93–104.
Ritchie, G. A.; Dunlap, J. R. 1980. Root growth potential: its development and expression in forest tree seedlings. New Zealand Journal of Forest Science. 10: 218–248.
Soffer, Hillel; Burger, David W. 1988. Effects of dissolved oxygen concentrations in aero-hydroponics on the formation and growth of adventitious roots. Journal of the American Society of Horticultural Science. 113: 218–221.
Stone, E. C. 1955. Poor survival and the physiological condition of planting stock. Forest Science. 1: 90–94.
Stone, E. C.; Schubert, G. H. 1959. The physiological condition of ponderosa pine (*Pinus ponderosa* Laws.) planting stock as it affects survival and growth after cold storage. Journal of Forestry. 57: 837–841.
Thompson, B. E.; Timmis, R. 1978. Root regeneration potential in Douglas-fir seedlings: effect of photoperiod and air temperature on its evaluation and control. In: Riedacker, A.; Gagnaire-Michard, J., eds. Proceedings, IUFRO symposium on root physiology and symbiosis; Nancy, France: 86–109.

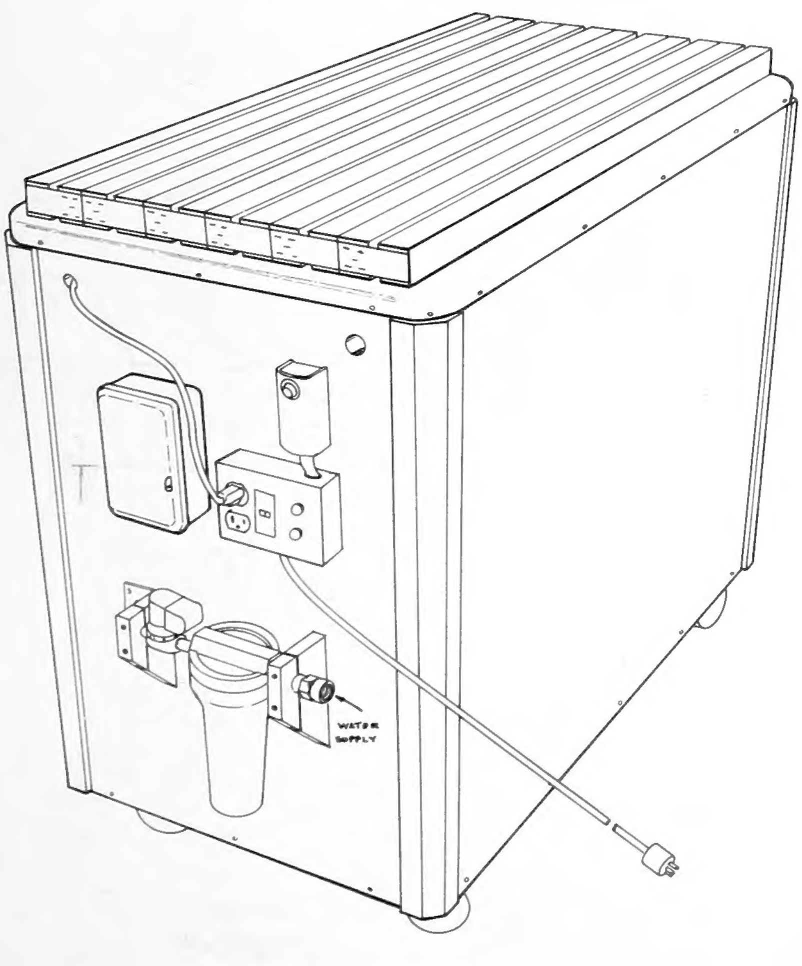
Appendix A: Construction and Use of the Aeroponic RGP Testing System

Design Overview

The device (fig. A-1) consists of an insulated tank containing a 8-1/2-inch-deep heated water reservoir in the bottom, a water heating system, a misting system, and seedling holders. Seedlings are clamped at the root collar in padded holders, which are laid across the top of the chamber. Roots are suspended in the atmosphere of the chamber and are kept moist by regular misting. The system uses tapwater and does not provide supplemental mineral nutrients.

Construction

Diagrams and materials lists for the four component systems of the aeroponic RGP system are provided in figures A-2 to A-5 and table 1. Each component system is discussed separately; numbers in parentheses are keyed to the materials list for the respective system. Materials used are dimensioned in English units. Outside dimensions of the design presented in appendix A are 42-1/2 inches high by 28-1/4 inches wide by 51-3/4 inches long; inside dimensions are 35-1/2 inches high by 23-1/4 inches wide by 46-3/4 inches long.



AEROPONIC RGP SYSTEM

Figure A-1.—The aeroponic RGP system.

Mist Chamber (fig. A-2)

The chamber consists of a polyethylene liner (2) insulated on the outside with rigid polyurethane foam board (7) and sheathed with plywood (4–6) (see section AA). The four vertical corners of the housing are shaped from 4-inch by 4-inch fir wood (3). A wood standoff (15) holds a water filter and solenoid valve. The misting chamber is equipped with castors (12) and is sized so that it can be moved through normal door openings. Alternative less expensive materials that can be used for the chamber are a metal trough or aluminum-faced urethane foam board cemented and sealed with silicone caulk/adhesive.

Misting System (fig. A-3)

A water supply connects to the device via a suitable length of garden hose. Water flows through the device through a filter (20), an electrically operated valve (23), an inlet through the chamber wall (26–30), a 25-foot heating coil of submerged garden hose (31), a misting manifold (32–43), misting nozzles (44), and a water level drain through the chamber wall (46–50). The misting manifold is constructed of standard CPVC plastic fittings, and includes a water hammer (39, 42) to absorb jolts in water pressure. The misting nozzles shown are Baumac ULV fog (coarse), which are inexpensive and work well at water pressures of 35–100 psi. The water level drain is located 9 inches above the chamber floor to maintain a 8-1/2-inch-deep reservoir in the bottom of the chamber. A fitting (50) on the outlet connects to a garden hose leading to a drain. A tank drain (52–55) allows complete draining and cleaning of the system.

Electrical System (fig. A-4)

The incoming 110-volt power cable (58–60) is connected to a ground fault interrupter (67). Wiring connections from the ground fault interrupter lead to a thermostat (69) that controls heating and to a timer (57) that controls misting via a solenoid valve (23). The remote bulb thermostat controls current via two receptacles (66) to two 250-watt aquarium heaters (76).

Seedling Holders (fig. A-5)

One tree holder consists of two square fiberglass tubes (80), plastic stops (82) attached to the underside (to prevent them from slipping into the chamber), soft open-cell foam (83) glued to one edge of each fiberglass tube, and a Velcro fastening system. The hook tape (84) is attached to the ends of the holders, and the removable pile tape (85) is used to secure them.

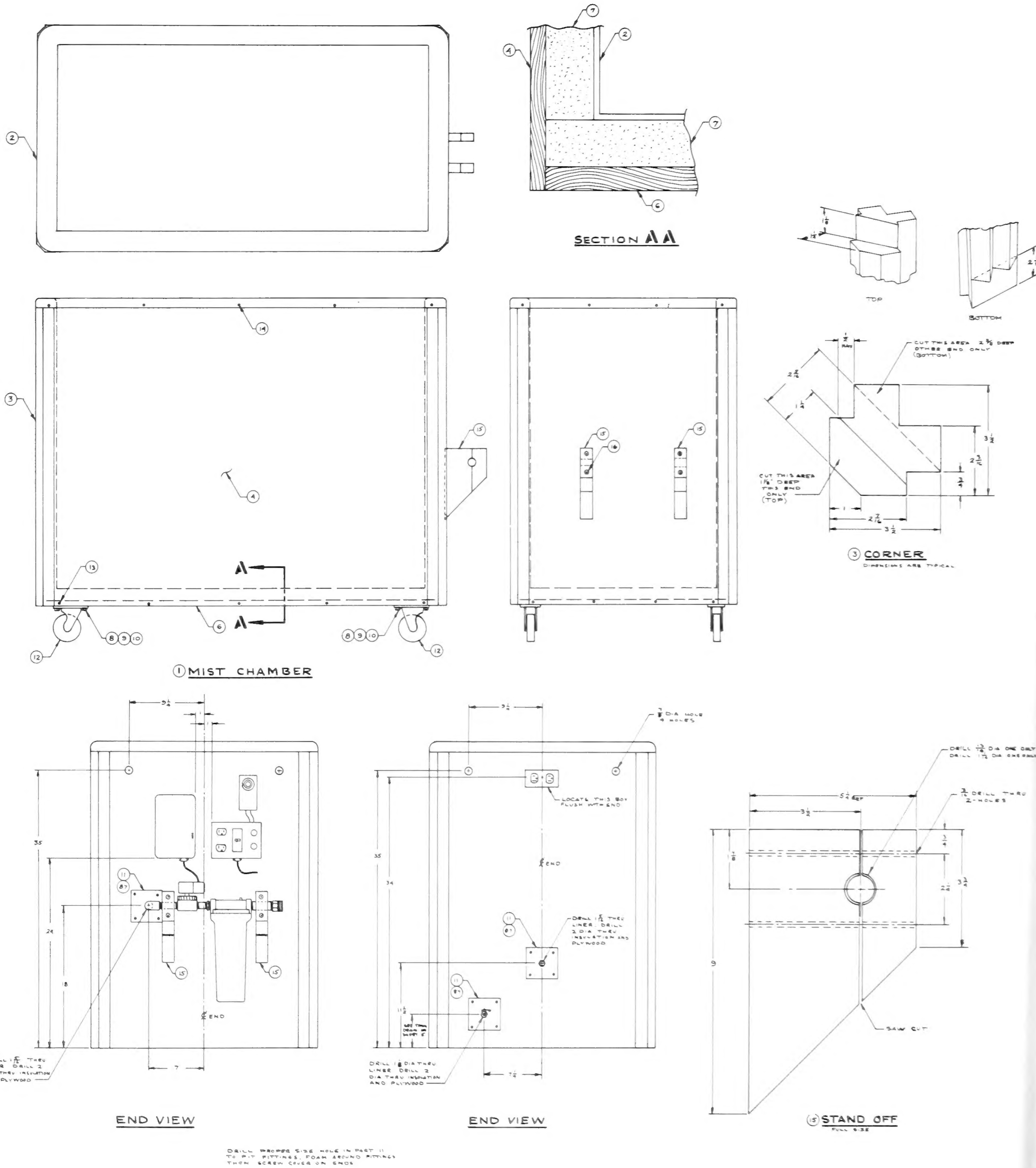
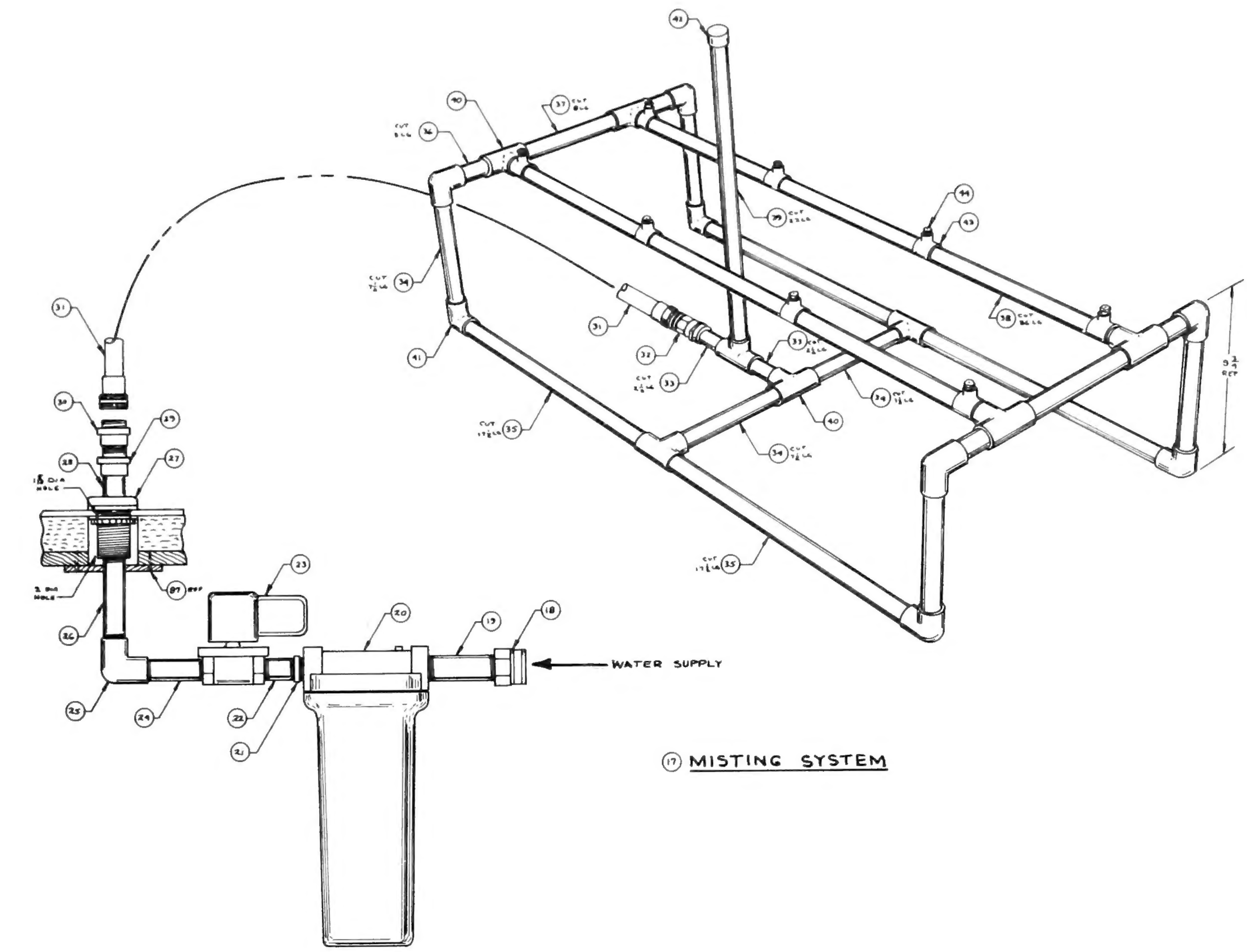
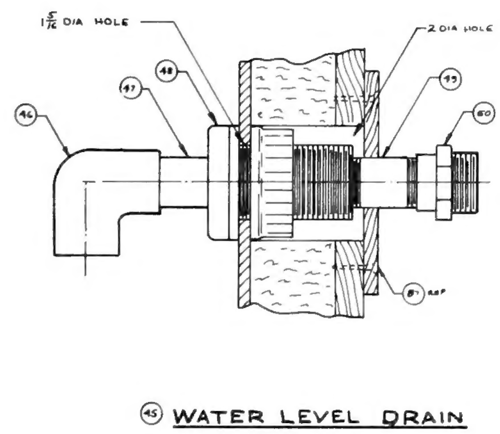
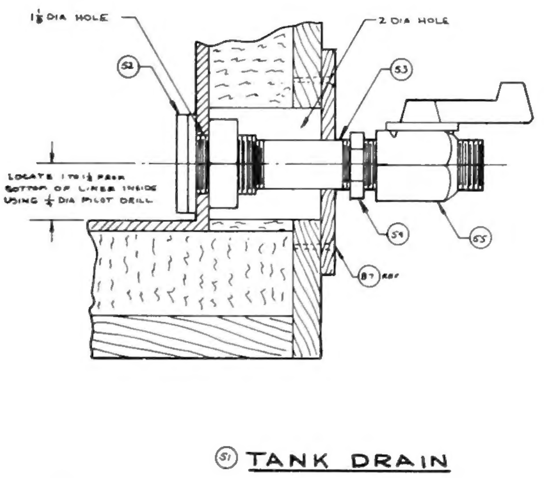


Figure A-2.—Mist chamber construction details.







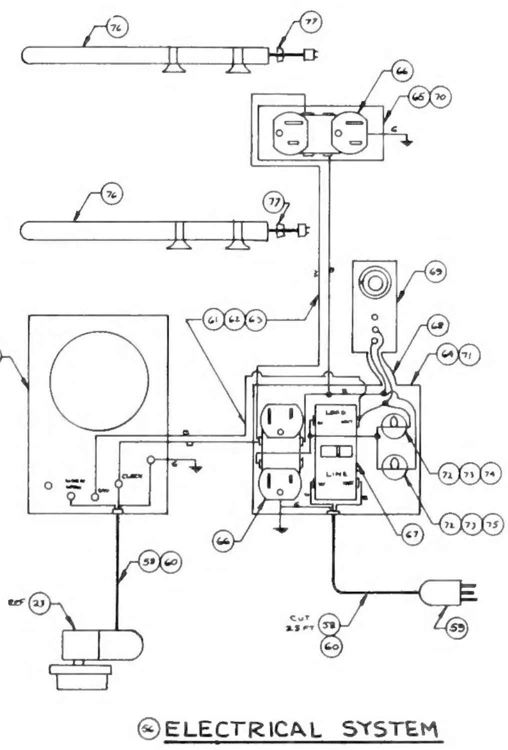


Figure A-3.—Misting system construction details.

Figure A-4.—Electrical system construction details.

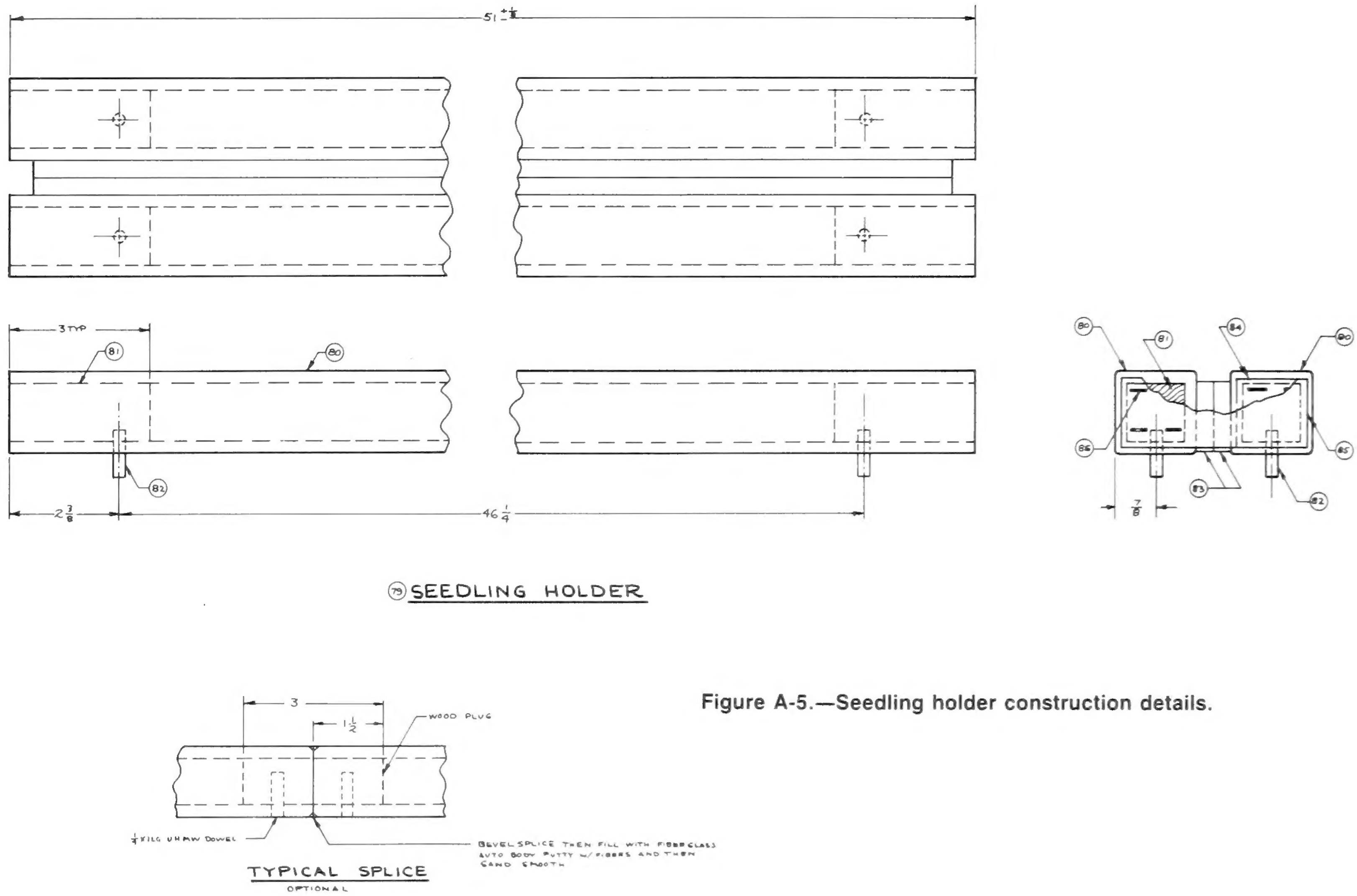


Figure A-5.—Seedling holder construction details.

Operation of the Root Misting Chamber

The device may be located where the following can be supplied: (1) a 110-volt/15-amp power source, (2) water via a garden hose connection, (3) a drain, and (4) repeatable air temperature and light conditions suitable for plant growth. The device is set up as follows: (1) the chamber is filled with 8-1/2 inches of water, (2) the thermostat is set to the desired water temperature (above room temperature), (3) the timer is set to the desired misting interval, and (4) water and power supplies are connected.

Two aquarium heaters combined with preheated misting water distribute the heat and maintain uniform temperature and humidity, eliminating the need for forced circulation. Incoming water is filtered to prevent clogging of the misting nozzles. Eight misting nozzles are used to avoid dry spots in the event of nozzle blockage. An initial misting interval of 10 seconds/10 minutes is suggested. An underwater entrance to the outlet is used to prevent fouling and possible flooding of the misting nozzles.

Sample seedlings are placed in the tree holders with the root collar on the soft foam. The holder is closed, compressed slightly, and secured with the fastening tape. Holders with seedlings are set on top of the chamber so that roots are suspended inside the chamber. The top of the chamber must be kept completely covered during the test to exclude light and to maintain the internal environment.

The system is calibrated to a target of known area, e.g., a piece of black paper 50 cm^2. Adjust the "$x2^n$" and "calibration" dials on the area meter so that the display area is 10 times the area of the target. One decimal place is obtained by dividing the reading by 10. Because seedlings are remeasured, it is very important that all instrument settings be recorded and routinely checked.

Appendix B: Use of a Portable Data Collector with the Area Measurement System

Area measurements can be transmitted to a portable data collector via an optional RS-232 serial port on the area meter. Set common protocol on the two devices (e.g., 4800 baud, even parity, half duplex, 7 data bits, 1 stop bit). A short program must be written for the data collector to accept and file the data. Following is an example program, DELTAT.3, written for the Polycorder (Omnidata International, Logan, UT[2]) to record three area measurements in the format XXX.X. The program accepts the current reading, divides it by 10, and files the data.

[2] The use of trade or company names in this publication is for reader information and does not imply endorsement by the U.S. Department of Agriculture of any product or service.

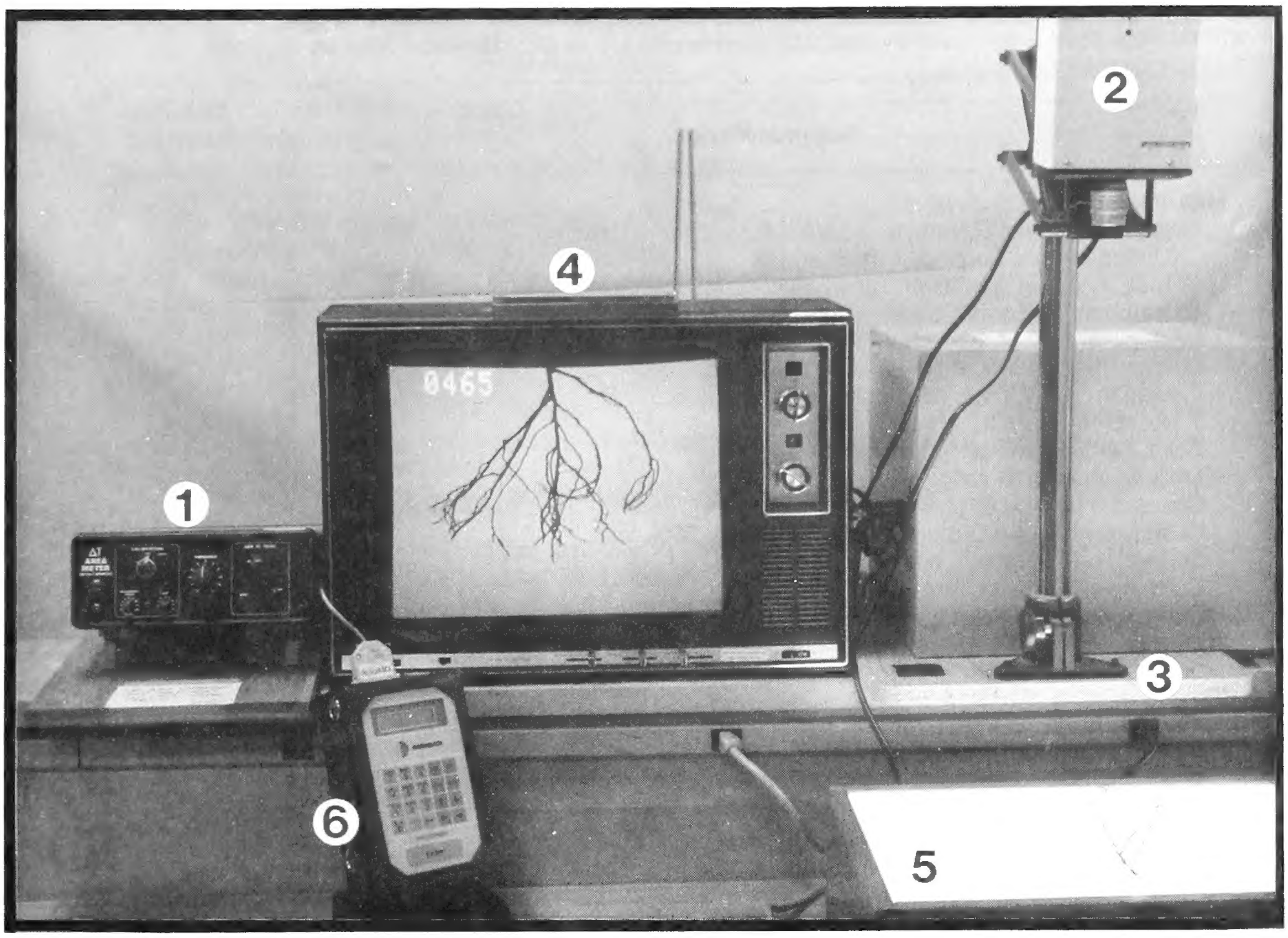


Figure B-1.—The area measurement system consists of: (1) digitizing area meter, (2) black-and-white high-resolution video camera, (3) camera stand, (4) black-and-white monitor, and (5) light box. Data may be transmitted from a serial port on the area meter to a portable data collector (6).

	PGM	Required by Polycorder
	DELTAT.3	Program name
1.	OPN (data file name)	User supplies name of data file
2.	CON 3	
3.	STO 1	Initiate counter for 3 repetitions of the loop
4.	VUF	Display file with page number, prompt, and line number
5.	CON 10	
6.	PSH	
7.	PSH	Divide the current reading by 10 to create one decimal place
8.	RDA	
9.	XAB	
10.	DIV	
11.	STF	Store data in file
12.	CDS 0,32	
13.	VUF	Display recorded data for 3 seconds
14.	DLY 30	
15.	CDS 0,32	
16.	ICP	Position file for the next measurement
17.	VUF	
18.	DJN 1,4	Decrement counter by 1, repeat steps 4–17 if result = 0
19.	ICP	After 3 measurements have been recorded in adjacent columns, the file is positioned to receive data for the next seedling
20.	DCP	
21.	DCP	
22.	DCP	
23.	JMP 2	Repeat the program for the next seedling
24.	END	Required at end of program
	#	End of file character

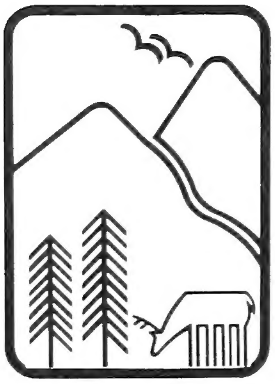
Table A-1.—Materials needed to construct an aeroponic RGP chamber 42–1/2H × 28–1/4W 51–3/4L. All dimensions are in English units; AR = as required.

Assembly item	Part number	Quantity required
Mist chamber (parts 2–16, 87)		
Liner, rectangular polyethylene tank 48L × 24W × 36H with 2" wide flange (United Plastic Corp -06119 or equal)	2	1
Corner, 4 × 4 × 38–1/8/8L, fir wood	3	4
Sides panel, 1/2 × 47–3/8W × 38–1/8H, AC plywood	4	2
Ends panel, 1/2 × 23–9/16W × 38–1/8H, AC plywood	5	2
Bottom, 3/4 × 27W × 50–3/8L, AC plywood	6	1
Insulation, 1–1/2 thick rigid polyurethane board	7	AR
T Nut, 5/16–18 NC	8	12
Bolts, 5/16–18 NC × 1, hex head	9	12
Lock washer, 5/16 split	10	12
Cover, 1/4 × 4 × 4, plywood	11	3
Caster, swivel, 3–1/2 dia × 1–5/16W wheel, 250- load	12	4
Screws, 1–5/8 drywall, coated	13	AR
Screws, -10 × 1, square drive head, plated	14	AR
Stand off, 2 × 6 wood	15	2
Screws, 6L drywall, coated	16	4
Screws, 1L drywall, coated	87	12
Misting system (parts 18–44)		
Adapter, brass, 3/4 NPT female × 3/4 garden hose female	18	1
Nipple, schedule 40 plastic, 3/4 × 1/2L	19	1
Water filter, Ametex model PSCL-31 or equal, polyester element	20	1
Bushing, schedule 40 plastic, 3/4 × 1/2 NPT	21	1
Nipple, schedule 40 plastic, 1/2 × 2	22	1
Solonoid valve, 1/2 NPT forged brass body, 115/1/60 (E.C. Geiger -34-GP412 or equal)	23	1
Nipple, schedule 40 plastic, 1/2 × 3	24	1
Elbow, schedule 40 plastic, 90°	25	1
Nipple, schedule 40 plastic, 1/2 × 4	26	1
Tank fitting, 1/2 rigid PVC, (US plastic -16441 or equal)	27	1
Nipple CTS-CPVC plastic, 3/4 × 2	28	1
Adapter, 3/4 NPT male × 3/4 female CTS-CPVC plastic	29	2
Adapter, brass, 3/4 NPT female × 3/4 garden hose male	30	1
Hose, 5/8 dia garden hose × 25 ft long	31	1
Adapter, brass, 3/4 NPT female × 3/4 garden hose female	32	1
Nipple, CTS-CPVC plastic, 3/4 × 2–1/2	33	2
Nipple, CTS-CPVC plastic, 3/4 × 7–1/2	34	6
Nipple, CTS-CVPC plastic, 3/4 × 17–1/2	35	4
Nipple, CTS-CPVC plastic, 3/4 × 3	36	4
Nipple, CTS-CPVC plastic, 3/4 × 8	37	2
Nipple, CTS-CPVC plastic, 3/4 × 36	38	2
Nipple, CTS-CPVC plastic, 3/4 × 22	39	1
Tee, 3/4 CTS-CPVC plastic pipe fitting	40	8
Elbow, 3/4 CTS-CPVC plastic, 90° pipe fitting	41	8
Cap, 3/4 CTS-CPVC plastic pipe fitting	42	1
Pipe saddle, 1/2 PVC pipe saddle with 1/8 NPT female	43	8
Nozzle, Baumac ULV fog mist nozzle coarse (A.H. Hummert -19-2035 or equal)	44	8
Elbow, 3/4 CTS-CPVC plastic, 90° pipe fitting	46	1
Nipple, CPVC plastic 3/4 × 2	47	1
Tank fitting, 1/2 rigid PVC (US plastic -16441 or equal)	48	1
Nipple, schedule 40 plastic, 1/2 × 2	49	1
Adapter, brass 1/2 NPT female × 3/4 garden hose male	50	1
Tank fitting, 1/2 rigid PVC (US plastic -16403 or equal)	52	1
Nipple, schedule 40 plastic, 1/2 × 2–1/2	53	1
Adapter, schedule 40 plastic, 3/4 × 1/2 NPT	54	1
Valve, brass, 1/4 turn shutoff, 3/4 NPT female × 3/4 garden hose male (A.H. Hummert -19-0050 or equal)	55	1

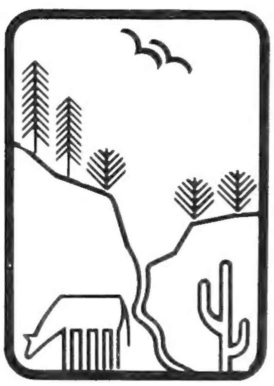
Assembly item	Part number	Quantity required
Electrical system (parts 57–53)		
Timer, 10-min cycle (W.W. Granger -2E355 or equal)	57	1
Cord, 14 gauge/3 wire, SO or SJ	58	2
Plug connector, std. straight blade plug, 125V, 15A, 3 blade	59	1
Cable connector, 1/2 nonmetallic sheathed	60	3
Wire, black 14 ga stranded, THHN	61	AR
Wire, white 14 ga stranded, THHN	62	AR
Wire, green 14 ga stranded, THHN	63	AR
Box, 3 gang 5-3/4 w × 2-1/8 D SW box	64	1
Box, handy box, 1-1/2D × 2-1/8W × 4L UN-58451-1/2	65	1
Receptacle, commercial grade duplex, ivory	66	2
GFI, feed thru ground fault (Levitron -6590-J or equal)	67	1
Offset nipple, 1/2 offset	68	1
Thermostat, single stage, 30–110°F range, 3-1/2° differential with 6-ft remote sensing bulb	69	1
Cover, for duplex flush receptacle UN-58-C-7	170	1
Covers, P&S -PSE-8-1, PSC-26-1, and PSE-14-1	71	1 ea
Holder, 125 series -125-0408-11-145 lamp holder	72	2
Lamp, NE51H (B2A)	73	2
Lens, 125-1133-403 amber	74	1
Lens, 125-1131-403 red	75	1
Heater, 250W -80 Jäger aquarium heater	76	2
Plug, rubber stopper with hole (McMaster -9545KB1)	77	12
Plug, rubber stopper solid (McMaster -9545K17)	78	2
Seedling holders (parts 80–86)		
Tube, 1-3/4 square × 1/4 wall, fiberglass	80	12
Plug, 1-1/4 square × 3, wood	81	24
Stop, 1/4 dia × 1 plastic rod UHMW	82	24
Rubber, 5/16 × 1-1/2 × 50L rubber weather strip	83	AR
Velcro hook, 1-1/2 square	84	24
Velcro pile, 1-1/2 × 4	85	12
Staples, 3/8L	86	AR

U.S. Department of Agriculture
Forest Service

Rocky Mountain Forest and Range Experiment Station



Rocky Mountains



Southwest

Great Plains

The Rocky Mountain Station is one of eight regional experiment stations, plus the Forest Products Laboratory and the Washington Office Staff, that make up the Forest Service research organization.

RESEARCH FOCUS

Research programs at the Rocky Mountain Station are coordinated with area universities and with other institutions. Many studies are conducted on a cooperative basis to accelerate solutions to problems involving range, water, wildlife and fish habitat, human and community development, timber, recreation, protection, and multiresource evaluation.

RESEARCH LOCATIONS

Research Work Units of the Rocky Mountain Station are operated in cooperation with universities in the following cities:

Albuquerque, New Mexico
Flagstaff, Arizona
Fort Collins, Colorado*
Laramie, Wyoming
Lincoln, Nebraska
Rapid City, South Dakota
Tempe, Arizona

*Station Headquarters: 240 W. Prospect Rd., Fort Collins, CO 80526